Impact of Local Climate on Sugarcane Water Footprint: A Case study of Dangote Sugar Company Numan, Nigeria

Obi, J. N. and *Zemba, A. A.
Department of Geography, School of Environmental Sciences,
Modibbo Adama University of Technology Yola, Nigeria
*Correspondence email: aa_zemba@mautech.edu.ng

Abstract

Assessing the impact of climate on agricultural water demand is essential. Water footprint as an indicator provides a different methodology to the assessment of agricultural water consumption under variability of climate. Here, we analysed the impact of climate variability on the water footprint of sugarcane in Dangote Sugar Company, Numan during 1981-2013. Data used were that of climate, soil and crop parameters. For the soil and crop parameters, the data were unavailable. However, CROPWAT package of the Food and Agricultural Organization contains data on those parameters for different ecological zones that include the study area.. This was used, in addition to 33 years' climatic data obtained from the Agriculture Department of the Company to model the impact of climate variability on water footprint of sugarcane. Further assessment of this was carried out using the SPSS and SPSS AMOS 21 statistical packages. Results show that there is an evidence of climate variability in the area. Crop evapotranspiration and irrigation water requirements of sugarcane in the study area presented an uptrend and this is due to the variation in climate. Calculated green water footprint (102 m^3/ton) and blue water footprint (172 m^3/ton) were lower than the global average of 139m^2/tons and 57m^2/tons respectively. Calculated total (274m^2/tons) is also greater than the global average of 210m^2/tons. Climatic factors generally account for 17% of the variation in water footprint of sugarcane under the study period. It was established from the results that out of the climatic elements investigated, rainfall is most influential to variations in water footprint of sugarcane. However, there are other agricultural management factors that may also have an effect on it, even higher than that of climate. It was recommended that attention should be given to adaptation of effective strategies to reduce the agricultural production risk associated with climate change in the long run.

Keywords: Climate, CROPWAT, Numan, Sugarcane, Water Footprint

INTRODUCTION

The world has over the past decades experienced a continuous deterioration in climatic condition due to its increasingly persistent changes. Climate change, agriculture and water security are now a global subject of concern. Climate change and global warming have further contributed in intensifying water challenges especially for the arid and semi-arid zones (Kim, 2012). This has led to a diminishing of fresh water supplies annually. Climate change most likely increases water scarcity by reason of modifications in the patterns and intensity of precipitation. Arid and semi-arid areas are therefore projected to turn out significantly drier, resulting in intensified water scarcity. Most of the world populations depend on rain-fed agriculture, hence changes in the magnitude of rainfall affects their livelihoods. A new Massachusetts Institute of Technology study also shows that reduced precipitation in some arid regions could trigger exponentially larger drops in groundwater tables (Morrison *et al.*, 2009).

Fresh water is a necessary requirement for all economic activities especially for agricultural purposes. Agriculture on the other hand has been identified as a major water using sector accounting for over 70% of global water withdrawals (FAO, 2011; Dourte & Fraisse, 2012; Zoumides *et al.,* 2014). Effects of climate change on water resources availability and quality will have an impact on several sectors of the economy including agriculture, energy production and ecosystems (Adams and Peck 2008). The water need per unit of product depends on both climate and water use efficiency.

In 2002, Allan Hoekstra introduced the Water Footprint (WF) indicator as a means to represent the water use for commodities. The WF of a commodity is thus defined as the aggregate volume of freshwater used throughout the production process. Water use for crops comprise largely of water (green and blue water) consumed during the growing period and grey water, that is the volume of water required to dilute a certain amount of pollution for it to meet ambient water quality standards (Hoekstra and Chapagain, 2008).The water footprint is a helpful tool in the quantification of water use through a process. It provides valuable insights into the component and location in a process having the largest water consumption (Ene *et al.,* 2012).

Sugarcane (*Saccharum officinarum*.) is a very important crop globally. This is owing to its immense usefulness in the daily consumption of any society as well as for industrial purposes of small, medium and large scale production. Girei and Giroh (2013) acknowledged that sugarcane contributes around 60% of the total global sugar demand whereas the remaining 40% comes from sugar beet. Aside from the production of sugar, the sugarcane crop is a suitable raw material in the production of biofuels such as ethanols that is useful in the reduction of dependence on fossil fuels and possibly mitigates climate change (GAIN, 2013).

Some of the main concerns for many stakeholders in climate and environmental resource issues have to do with climate change and natural resources that include sugarcane. Because climate affects the availability and sustainability of these natural resources like water, directly or indirectly, it is only smarter to be proactive. Proper know-how on their nature and extent and nexus will create a basis for informed decision if these resources will serve humanity for the coming generations. However, there is a general widespread quest for cognizance vis-à-vis sustainability standards. One area of sustainability that has drawn a lot of attention in recent years is that of climate change and resource utilization. It is expected that in the long run, conforming to such standards will save money, as resources are used more responsibly and a cut back on waste and pollution is achieved.

Study Area

The study area, as shown in Figures 1, is an area located between latitudes 9º22′00″ N and 9º38′00″ N and longitudes 11º45′00″ E and 12º00′00″ E, covering the farm and factory of the Dangote Sugar Company (formerly Savannah Sugar Company). The Dangote Sugar Company being the main focus of the study is located north of the River Benue and about 20km North of Numan town in Adamawa state, Northeast Nigeria (Savannah Sugar Company Ltd., 2014). It lies at an elevation of 150m above sea level (Mirchaulum and Eguda, 1995). The company has a land mass of about 32,000 hectares spread, along Yola-Gombe highway. The out-grower farms of the Savannah Sugar Company are situated in five out-grower zones, respectively managed by estate mangers. They include Zekun, Gyawana, Lafia, Danto and Opallo estates. Irrigation is done by the use of irrigation water from Kiri Dam (Figure 1), connected by a 30km distance canal to the sugar cane estate and commences two to three weeks after the rainfall cessation (Gireh & Giroh, 2013).

The climate of the area is semi-arid characterized by wide seasonal and diurnal temperature ranges. There are two main marked tropical seasons. The wet season, lasting from April-October and dry season lasts from November to March. The mean rainfall of about 905mm is recorded with peaks in August and September (Yahaya, 2013; Binbol *et al.*, 2006). Between November and January the Harmattan pushes the Inter-tropical Discontinuity (ITD) to its most southerly latitudinal position of 2-5°N. Throughout this period, most of Adamawa State is influenced comparatively by stable dry continental air mass from the northeast and hence rainfall is absent or very low (Adebayo, 1999). The average monthly temperature is 26.9°C, with minimum temperature of 18°C and a maximum of 40°C (Binbol *et al*, 2006).

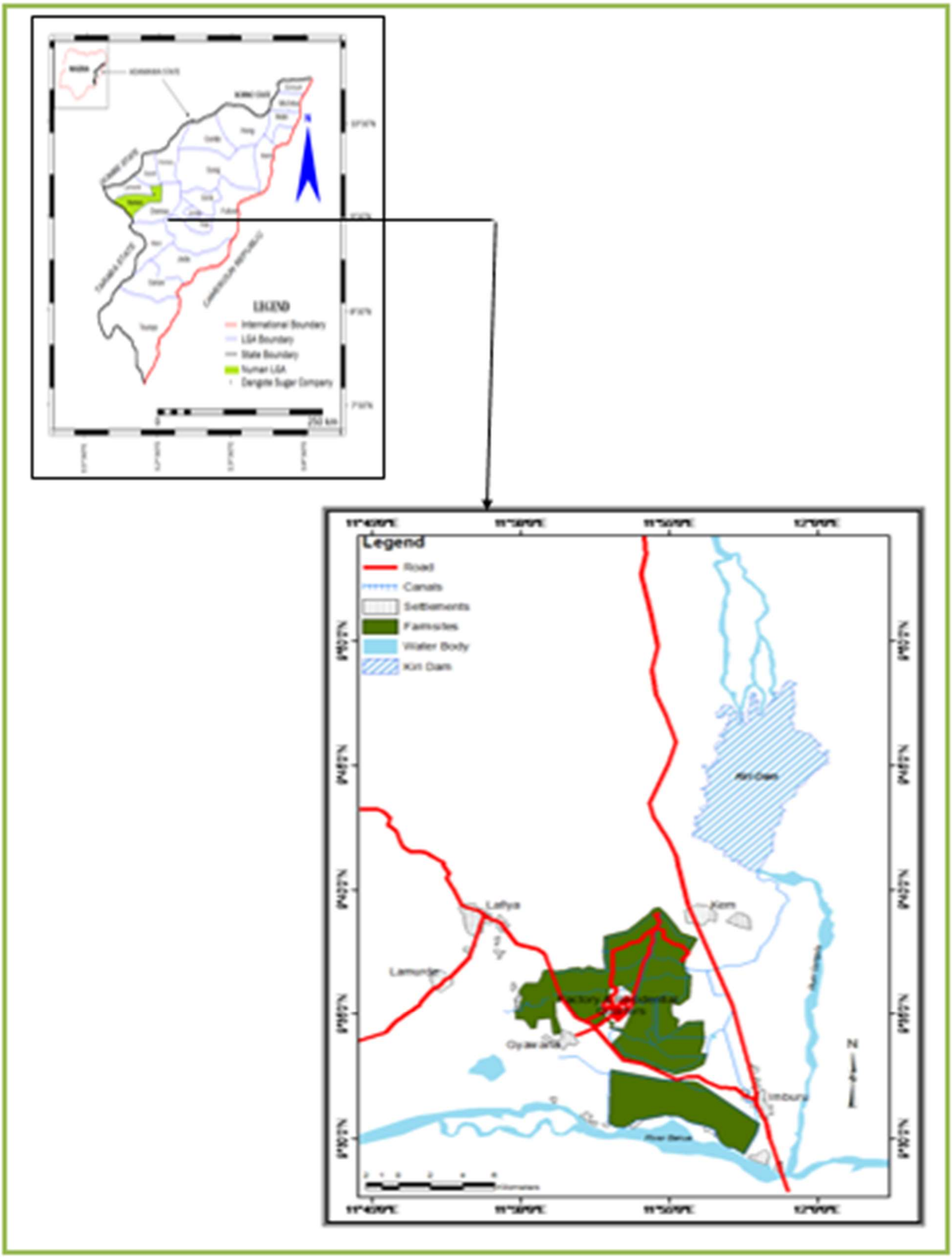

Figure 1: Dangote Sugar Company Numan, Nigeria

The study area has good and favourable soil made up of alluvial and vertisol soils that support sugarcane production (Tukur and Adebayo, 1997). Gireh and Giroh (2013) reported that the vertisols of the area are derived from quaternary alluvium underlain by the Bima sandstones found on nearby level plain. However, Mirchalum and Eguda (1995) reported that the vertisols owe their origin to the olivine basalts of the Lunguda plateau. The vertisol soils is that which is present in depressions and low-lying areas, which are usually heavily dark soils derived majorly from argillaceous sediments, rich in iron concentration and deep wide cracks when dry. This type of soil is structurally sticky, with colours between dark gray. Virmani (1987) made reference to the high productivity of vertisols if managed properly and also their relative susceptibility to erosion and suggested that climatic parameters should be studied alongside soils for better understanding of crop environment in regions with vertisol.

MATERIALS AND METHODS

In this section, data types, sources, modeling techniques are described in the following subsections:

Types and Sources of Data

The data required were basically on climate, crop and soil parameters (Table 1), all of which are secondary in nature. These data were obtained from several sources including the Dangote Sugar Company agriculture department, relevant literature and the FAO CROPWAT directory contained in the package available for download on FAO site (www.fao.org).

Climatic, Soil and Crop Data

The climatic data of rainfall, temperature, humidity, sunshine hours and wind speed for 33 years period (1981-2013) was obtained from the Agriculture Department of the Dangote Sugar Company. Specific crop parameters of crop coefficients in different crop development stages (initial, middle and late stage), the length of each crop in each development stage, the root depth as seen in Table 1 were not available from the sugarcane farms, hence the need for modeling. Planting dates for the study area were adopted from Binbol *et al.* (2006), crop coefficient (Kc) for different crop development stage and the length of growth stage were derived from CROPWAT package. Soil parameters needed for a vertisol tropical soil was also adopted from the directory of the CROPWAT package. Data on soil parameters of a black clay soil which is similar to the vertisols found on the sugarcane farms was adopted from FAO (2014). A very essential means for calculation of water footprint of sugarcane was the data on yield of sugarcane for 33years (1981-2013) using Hoekstra (2003) and Allen *et al.* (1998) methods.

CROPWAT Model

CROPWAT is a decision support tool developed by the Land and Water Development Division of Food and Agricultural Organization (FAO). It is a computer program for the water requirements based on soil, climate and crop data (Merica, 2015). Data on crop evapotranspiration and yield are basics for the estimation of the water footprint in crop production. CROPWAT model, sourced from the FAO website was utilized to generate the reference evapotranspiration (ET_0 mm/day). This model applies the FAO *Penman-Monteith* method which is selected as the method by which the evapotranspiration of the reference surface (ETo) can be determined unambiguously as the method which provides consistent ETo values in all regions and climates (Allen *et al.* 1998). Parameters required as input in the CROPWAT package are given in Table 1.

$$ETo = \frac{0.408\Delta\,(R_n - G) + \gamma\frac{900}{T+273}u_2\,(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \quad (1)$$

ET_o	reference evapotranspiration [mm day^{-1}],
R_n	net radiation at the crop surface [MJ m^{-2} day^{-1}],
G	soil heat flux density [MJ m^{-2} day^{-1}],
T	mean daily air temperature at 2 m height [°C],
u_2	wind speed at 2 m height [m s^{-1}],
e_s	saturation vapour pressure [kPa],
e_a	actual vapour pressure [kPa],
e_s-e_a	saturation vapour pressure deficit [kPa],
Δ	slope vapour pressure curve [kPa $°C^{-1}$],
γ	psychrometric constant [kPa $°C^{-1}$].

Table 1: Data Required for Inputting into CROPWAT Model

Type	Description	Unit	Data Source
Crop parameters	Crop coefficient (Kc_{ini}, Kc_{mid}, Kc_{end})	Dimensionless	FAO (2014)
	Length of growing season (Lini, Ldev, Lmid, Llate)	[days]	FAO (2014)
	Rooting depth (Zr_{max}, Zr_{ini})	[cm]	FAO (2014)
	Critical depletion	Dimensionless	FAO (2014)
	Yield response factor	Dimensionless	FAO (2014)
	Crop height (Hmax)	[m]	FAO (2014)
	Planting date	[date]	Binbol *et al.*, (2007)
Soil parameters	Total available soil moisture (FC-WP)	[mm/meter]	FAO (2014)
	Maximum rain infiltration rate	[mm/day]	FAO (2014)
	Maximum rooting depth	[cm]	FAO (2014)
	Initial soil moisture depletion	[%]	FAO (2014)
Climate parameters	Precipitation (monthly)	[mm]	Agric. Dept. DSC
	Sunshine hours (monthly)	[h]	Agric. Dept. DSC
	Humidity (monthly)	[%]	Agric. Dept. DSC
	Wind speed (monthly)	[m s^{-1}]	Agric. Dept. DSC
	Temperature (monthly): Maximum and minimum	[°C]	Agric. Dept. DSC

METHODOLOGY

The software used in the analysis includes SPSS 22, AMOS 21, Excel and CROPWAT 8.0. The impacts of climate change on the variation of Water Footprint for Sugarcane was analysed using SPSS package and Microsoft Excel. Usually, the FAO models (CROPWAT and AQUACROP) are used to estimate crop water use. CROPWAT model is simpler to use in assessing the relationship between water availability and climate factors. To compute the Reference evapotranspiration (ETo), crop evapotranspiration (ETc), Irrigation Requirements (IR) and Effective rainfall (Eff), the FAO method was used. The analysis was carried out through the following methods:

Water footprint calculation method:

The calculation adopted for this study was based on the approach by Gerbens-Leenes and Hoekstra (2009) and Scholten (2009) as follows:

(a) First, the green water component was calculated. This was done by determining the Crop Evapotranspiration (ET_c) which was determined by multiplying the Crop Coefficient (Kc) (which is dimensionless) by the reference Crop Evapotranspiration (ET_o) (mm/day) using the *Penman-Monteith* method (Allen *et al*, 1998) in CROPWAT model.

$$ET_c = K_C \times ET_O \quad [2]$$

(b) Next, estimating the Green Water Evapotranspiration, which is equal to the minimum of total ET_c and Effective Precipitation (Eff) and Blue Water Evapotranspiration (ET_{blue}), was calculated according to Hoekstra *et al.* (2011) and Dourte and Fraisse (2012):

$$ET_{green} = \min(ET_c, Eff) \quad [3]$$

$$ET_{blue} = ET_c - ET_{green} \quad [4]$$

(c) Crop water use (CWU), that is, the green (CWU_{green}) and blue (CWU_{blue}) component, which is the accumulation of daily evapotranspiration over the complete growing period (Hoekstra & Chapagain, 2008) was determined. The CWU in the CROPWAT model is given in millimetres (*mm)* and is converted into *m^3/ha* by multiplying it by the factor 10.

$$CWU_{green} = 10 \times \sum_{d=1}^{lp} ET_{green} \quad [5]$$

$$CWU_{blue} = 10 \times \sum_{d=1}^{lp} ET_{blue} \quad [6]$$

Therefore, to calculate the green and blue component of the water footprint of the sugarcane (m^3/ton), the crop water use is divided by the yield (Y, ton/ha):

$$Green\ Water\ Footprint\ (m^3/\text{ton}) = \frac{CWU_{green}(m^3/\text{ha})}{Y\ (\text{ton/ha})} \quad [7]$$

$$Blue\ Water\ Footprint\ (m^3/\text{ton}) = \frac{CWU_{blue}\ (m^3/\text{ha})}{Y\ (\text{ton/ha})} \quad [8]$$

The green and blue water are the major sources of crop water, therefore, the grey water was not considered. Calculation of grey water footprint was not considered due to unavailability of data. Average water footprint for sugarcane was obtained by summing up the average green and blue WF of sugarcane for the area of study (Eqn. 9).

Water Footprint = Green Water Footprint + Blue Water Footprint [9]

The result was compared with the global average generated by Mekonnen and Hoekstra (2011) to be able to place the status of the result for the study area.

Green and Blue Water Footprint

The green and blue water footprint results was subjected to trend analysis, equations and coefficient of determination (R^2) to analyse variability over time.

RESULTS AND DISCUSSION

Results and discussion of this research are presented in the following subsections:

Climate Variability

The study area displays variability in climate over the period 1981-2013. Breaking down climatic factors of rainfall, minimum and maximum temperatures, on a temporal scale before and after the sugar project, shows a general warming and drying of the climatic environment around the study area. Rainfall was found to be declining by about 2mm/year, indicated by negative trend line equation in Figure 2. This is indicative of a dry period. It agrees with Olaniran (2002) report which states that "5.0-7.5mm decline in the rainfall data of Yola-Enugu axis from 1971-2000" exists. It also corroborates Adebayo and Yahaya's (2015) findings, which had earlier agreed with that of Olaniran (2002).

Temperature was found to rise by about 0.08ºC per decade as seen in Figure 3 and this development may be attributed to the landuse change and other activities relating to the sugar manufacturing company. This finding confirms Adebayo (2010) report of a 0.867ºC rise in the temperature of Yola, Nigeria. On a global scale, Sachez-Lorenz (2009, in Adebayo & Yahaya, 2015) reported a 0.13± 0.03ºC change in mean surface temperature over 50 year period. This is a major sign of greater warming in majority of world regions. However, this warming is unevenly distributed globally. Climatic trends indicated that there has been a significant variation in climate of the entire area. The independent variable of time accounts for the variation in 23% of relative humidity, 62% of evaporation, 90% of sunshine and 32% of wind run. Between the months of August/September and February/March, the relative humidity reads as high as 77.9% and as low as 16.3% respectively. Sunshine hours of 6-8hr/day are enjoyed in the area, with high wind speed of 152 km/hr on the average and mean annual evaporation is approximately 10mm.

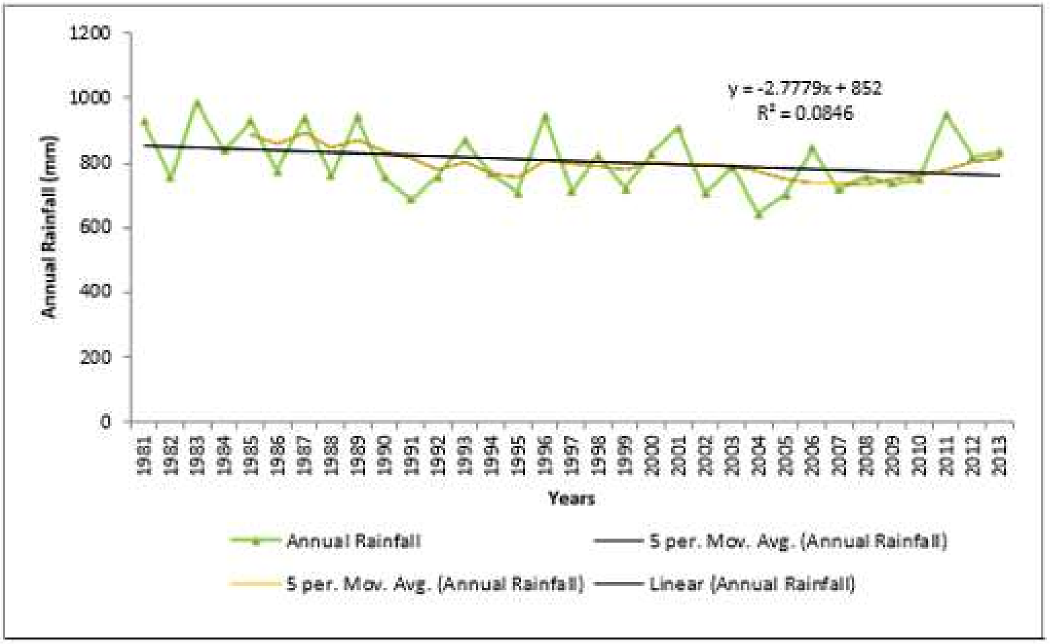

Figure 2: Trends of Mean Annual Rainfall at Savannah Sugar Project Company

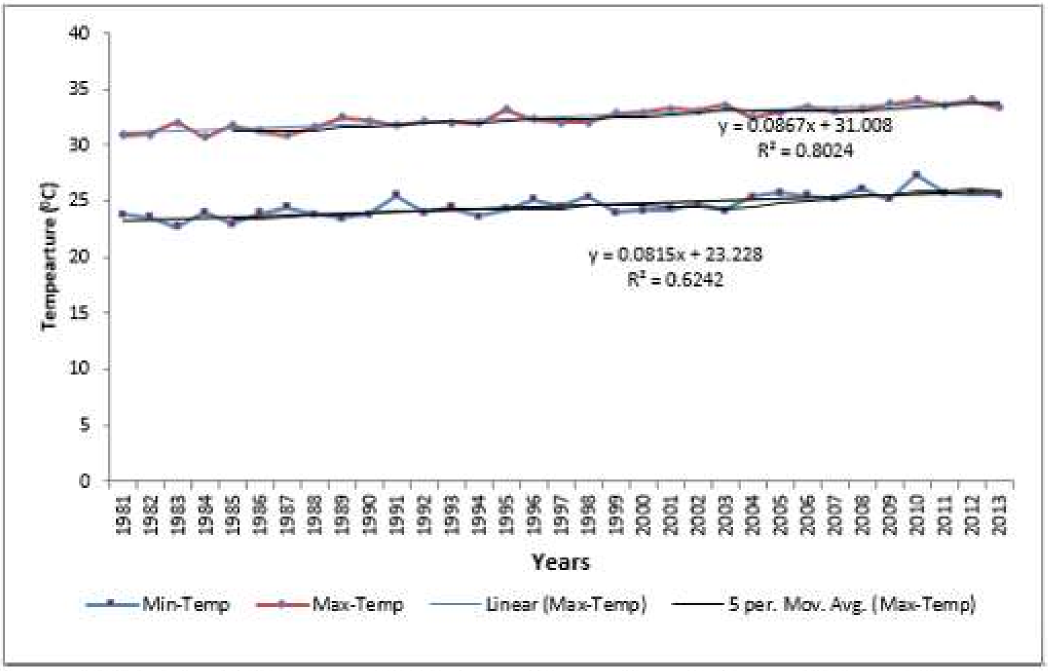

Figure 3: Trends of Minimum and Maximum Temperature at Savannah Sugar Company

Sugarcane Yield per Harvested Hectares

Figure 4 describes the fluctuation in yield of sugarcane per hectares cultivated for the period under study. The yield of sugarcane displayed a decline in trend. At initial stages of the sugarcane production, there was more yield from the fewer hectares cultivated than towards the later years where a visible decline in yield can be observed as compared to the hectares harvested. This may be partly due to soil depreciation over time which may have affected output of the crop and other influencing factors. There were no records for 1983/84, 1997/98 and 2003 – 2006 planting seasons because there were no production activities in the company.

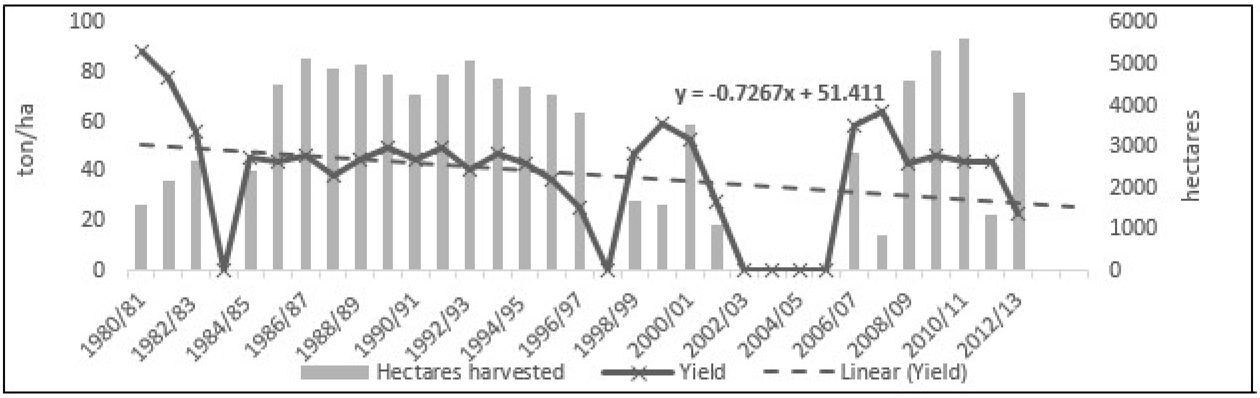

Figure 4: Distribution of Sugarcane Yield per Hectares Harvested 1981-2013

Water Footprint of Sugarcane

The results showed that the average crop water footprint for sugarcane in the study area for the multiple years 1981-2013 calculated were as follows: green water footprint 102 m^3/ton, blue water footprint 172 m^3/ton and the total water footprint 274 m^3/ton (Table 2). The years with the highest and lowest sugarcane WF_{blue} were 2013 (495.3m^3/ton) and 1981 (69.89m^3/ton) respectively.

The blue water footprint calculated for the study area (172 m ^{2}/mm) is higher as compared to the global average (57 m^3/ton). Also, it's higher than those of northern Thailand with 87m^3/ton, (Kongboon & Sampattagul 2012) and India with 104m^3/ton (Gerbens-Leenes & Hoekstra, 2012). This result agrees with Kim (2012) that Nigeria is one of the countries ranking high in water footprint especially for agricultural production due to efficient use of water. Reliance on irrigation water from the Kiri dam as a source of water may be the reason for the fluctuations observed in planting dates of sugarcane between March and June.

Generally, the years with the highest and lowest water footprint are 2013 (752 m^3/ton) and 1981 (148.7 m^3/ton) respectively. The estimations generated are based on different critical parameters and may not be an exact representation of the study area. Mekonnen and Hoekstra (2011) calculated and compared the WF of several agricultural crops and their derived products. Their calculated value is a global average that sugarcane uses 210 m^3/ton of water and this is smaller than the WF calculated with the parameters in this research. Mekonnen and Hoekstra (2011) mentioned that the ratio of green-blue WF of a crop is dependent on local green water availability. Hence, if a certain location is able to get adequate rain, achieving a certain global benchmark on consumption WF, that specific location will have a blue WF benchmark of zero. This implies that the lesser the rainfall below a certain point, the higher the fraction of blue water needed to achieve a certain water productivity of WF benchmark. The variances in the value of WF are also instigated by several factors, including climate, crop characteristics, agricultural production system all of which differ by regions (Gerbens-Leenes and Hoekstra, 2012; Kongboon & Sampattagul, 2012).

Table 2: Global and Dangote Sugar Company (DSC) Average Water Footprint of Sugarcane

	Sugarcane (m^3/ton)			
	Green WF	Blue WF	Grey WF	Total
DSC, Numan	102	172	-	274
Global average	139	57	13	210

Variation of green and blue water footprint

Figure 5 shows that green water footprint accounts for < 40% of the total WF for sugarcane in the study area while the blue water footprint accounts for the higher percentage of >50%. Generally, blue water footprint source, that is Kiri dam, contributes a significant 63% of the final water while rainfall contributes 37%. The cultivation style is basically that of dry season farming where irrigation is incorporated. Therefore, the production of sugarcane in the study area relies mainly on blue water resource (irrigation water). This is similar to a study by Ahmed and Ribbe (2011) who acknowledged the blue water as the leading contributor in the overall water footprints of the irrigated systems in Sudan.

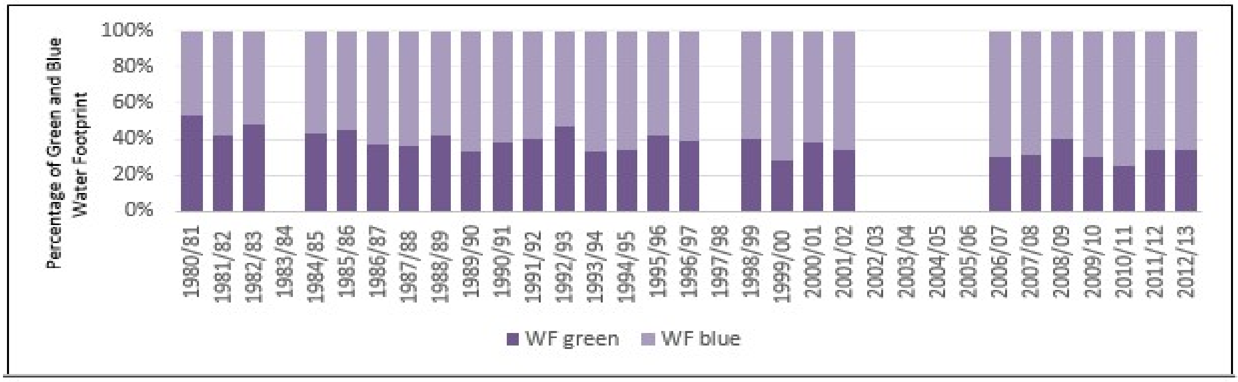

Figure 5: Percentage Distribution of Green and Blue Water Footprint of Sugarcane, 1981-2013

Impact of Climate Variation on Water Footprint

As stated earlier, the impact of climate variation was investigated on Crop Evapotranspiration (ETc), Effective Rainfall (Eff) and Irrigation Water Requirement (IR). From section 4.1 above, it has been established that the climatic elements of rainfall, temperature (minimum and maximum), relative humidity, wind speed and evaporation have experienced temporal variation over a period of time. ETc, Eff and IR are all heavily dependent on the major climatic elements and other parameters of crop and soil. They are also very key in the determination of water footprint. These variables are some sort of secondary independent variables affecting WF.

Figure 6 shows the variation of ETc, Eff and IR of sugarcane from 1981-2013 in the study area. ETc and Eff reflected a decline in trend. However, the percentage decline in ETc is almost negligible with about 0.1% while the decline in Eff is 6%. The IR indicated an increase in trend of 1.3%. The element of time being a predictor has very little effect it makes on the variables ETc, Eff and IR in relation to water footprint. The linear rates were 2mm decline for ETc, 4mm/year rise for IR and 6mm/year decline for Eff. This agrees with the findings of Adebayo and Yahaya (2015) of a 4.6mm/year decline in the rainfall of the Sugar Project area at Numan.

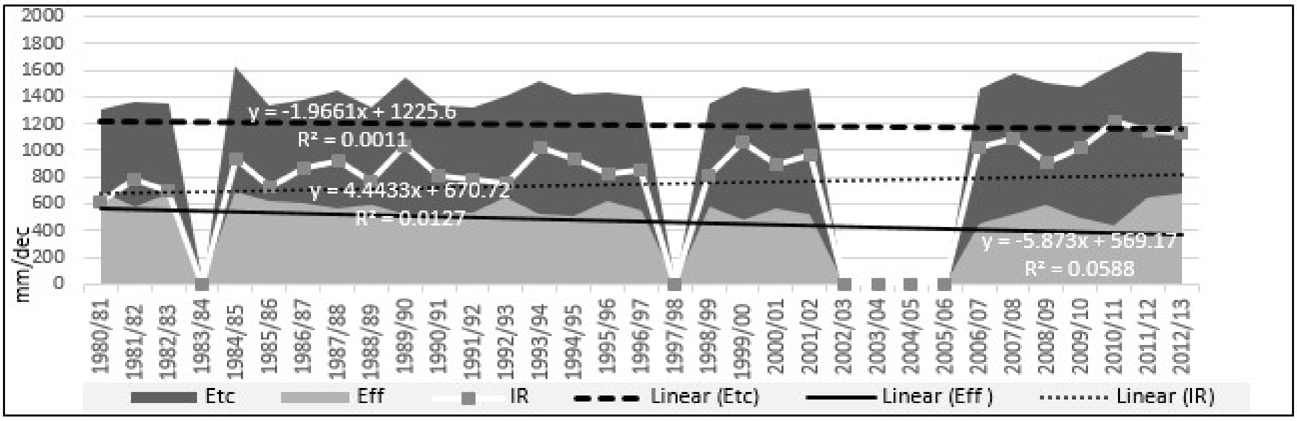

Figure 6: Interannual Variability of Crop Evapotranspiration (ETc), Effective Precipitation (E_{ff}) and Irrigation Water Requirements (IR) of Sugarcane

CONCLUSION

From the standpoint of water footprint components in the research area, the WF blue accounted for a larger proportion of the total water footprint of sugarcane than WF green. Invariably, the growing of sugarcane in the study area depends on the blue water source (irrigation water). The green water however has a lower opportunity cost than the blue water. Rainfall was observed as the most influential climatic element on the water footprint of sugarcane for the study area. This call for concern, as even the main source of blue water for the Sugarcane production, that is the Kiri dam, takes its source from the River Gongola, a major tributary to Benue River, which are observed to reduce in volume day by day. There is also an increase in run off during the rainy season, which more often than not wastes away unutilized. The direct and indirect implications may cumulate to a disadvantage for the production of sugarcane as it requires a lot of water to survive especially under a changing climate. The climatic factors were observed not to be the dominant factors that caused the increase of WF of sugarcane in the Dangote Sugar estates, Numan over the study period 1981-2013. The influence rate of climatic parameters put together was only 17%. The results further suggested that the water footprint of a crop also depends on crop parameters and agricultural production level rather than the local climate condition and its variation alone. However, effective measures should be taken to mitigate the adverse effects caused by climate change in the long run.

Based on the findings above, it was recommended that efforts should be intensified towards data collection and documentation. This is because there were cases of missing. A comprehensive water consumption scheme for the two water sources (rain and dam) should also be instituted to deal with opposing impacts of climate change. Finally, future prediction of water footprint should incorporate agro-managerial factors, rather than just crop, soil and climatic factors.

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